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(54) Title: PREPARATION OF TERTIARY PHOSPHINES VIA NICKEL-CATALYZED CROSS COUPLING		
$\text{R}^1\text{X}_n + \text{ClPR}^2\text{R}^3 \xrightarrow[\text{reductant}]{\text{catalyst}} \text{R}^1(\text{PR}^2\text{R}^3)_n \quad (I)$		
(57) Abstract <p>The invention is an improved method for the preparation of tertiary phosphines by way of cross-coupling of aryl, alkenyl, cycloalkenyl or aralkyl halides or aryl, alkenyl, cycloalkenyl or aralkyl sulfonate esters with chlorophosphines in the presence of a catalyst and a reductant. In general reaction scheme (I), R¹ is aryl, alkenyl, cycloalkenyl or aralkyl, any of which may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl, chloro, fluoro, alkoxy carbonyl, cyano, trifluoromethyl, cycloalkyl, or CONR⁴R⁵ wherein R⁴ and R⁵ are independently hydrogen, alkyl, aryl or aralkyl; R² and R³ are independently aryl, alkyl, aralkyl, any of which may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl, chloro, fluoro, alkoxy carbonyl, cyano, trifluoromethyl, cycloalkyl or CONR⁴R⁵ wherein R⁴ and R⁵ are independently hydrogen, alkyl, aryl or aralkyl; and n is 2 where R¹ is a difunctional moiety and 1 for any other R¹; and X is Cl, Br, I, or OSO₂Y; wherein Y is alkyl, trihalomethyl, phenyl, halophenyl, or alkylphenyl.</p>		

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TITLE

PREPARATION OF TERTIARY PHOSPHINES VIA NICKEL-CATALYZED CROSS COUPLING

BACKGROUND OF THE INVENTION

Field of the Invention

5 The invention relates to an improved method for the preparation of tertiary phosphines by cross-coupling of aryl, alkenyl, cycloalkenyl or aralkyl halides, or aryl, alkenyl, cycloalkenyl or aralkyl sulfonate esters, with chlorophosphines in the presence of a catalyst and a reductant.

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Related Background Art

Tertiary phosphines, especially triarylphosphines, are well known as ligands for transition metal catalysts. Preparation of tertiary phosphines typically proceeds by one of four methods: reaction of halophosphines with aryl Grignard reagents or organolithium reagents, metalation of diarylphosphines followed by reaction with aryl halides or aryl sulfonate esters, Friedel-Crafts reactions of halophosphines with activated

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aromatic rings, and cross-coupling of aryl halides or aryl triflates with diarylphosphines.

Reactions of aryl Grignard reagents or organolithium reagents with halophosphines are limited to cases in which there are no functional groups present on the aryl moieties which react with the Grignard reagents, such as halo, alkanoyl, or ester substituents. In addition, this method requires special handling procedures for the moisture-sensitive and relatively unstable Grignard reagents or organolithium reagents.

Preparation of tertiary phosphines by metalation of diarylphosphines also requires handling of Grignard or organolithium reagents, with the accompanying problems mentioned above, as well as special procedures necessitated by the fact that diarylphosphines are light-sensitive and pyrophoric. Another disadvantage of this method is that metalated diarylphosphines are extremely nucleophilic and will react with certain functional groups on the aryl moieties of the starting materials, such as halo and alkoxy substituents.

Friedel-Crafts reactions are disadvantageous because they typically employ extremely acidic catalysts such as aluminum bromide, aluminum chloride, ferric chloride, or sulfuric acid. Such catalysts may be incompatible with a variety of functional groups on the aryl moieties. In addition, these catalysts are corrosive and moisture-sensitive, and thus difficult to handle.

As previously mentioned, cross-coupling of aryl halides or triflates with diarylphosphines to produce triarylphosphines is also known.

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Tunney and Stille, Journal of Organic Chemistry, Vol. 52, page 748 (1987), prepared triarylphosphines by carrying out a palladium-catalyzed cross-coupling of aryl halides and either

5 (trimethylsilyl)diphenylphosphine or (trimethylstannyl)diphenylphosphine. The major disadvantage of this method is that (trimethylsilyl)diphenylphosphine and (trimethylstannyl)diphenylphosphine are pyrophoric, and

10 thus require special handling procedures. An additional disadvantage is that these reagents are expensive. A limitation of the method of Tunney and Stille is that the trimethylsilyl-substituted starting material, preferred due to the much greater toxicity of

15 the trimethylstannyl compounds, reacts with hydroxyl, amino, nitro, and aldehyde groups on the aryl moieties, preventing application of the method to preparation of triarylphosphines bearing these functional groups. Another limitation is that only aryl halides are used

20 as starting materials, and not arylsulfonate esters. Yet another limitation is that only triarylphosphines are produced by this method because only aryl halides are used as starting materials. There is no suggestion of using benzyl halides as starting materials to make

25 benzylarylphosphines.

A cross-coupling reaction to prepare triarylphosphines is also described in U.S. Patent No. 5,399,771, which discloses the use of a nickel-catalyzed cross-coupling

30 reaction of a 1,1'-bi-2-naphthol disulfonate ester with diphenylphosphine to produce 2,2'-bis(diphenylphosphino)-1,1'-binaphthyl. This reference exemplifies only the specific transformation mentioned above, and limits the disulfonate ester starting

35 material to the triflate, mesylate or tosylate; no suggestion is made of the possibility of using a halide starting material. A disadvantage of this method is

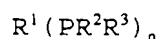
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that one of the starting materials, i.e., diphenylphosphine, is light-sensitive and pyrophoric, thus requiring special handling.

- 5 The use of diarylchlorophosphines as reagents in the catalytic preparation of tertiary phosphines is neither suggested nor exemplified by the aforementioned references.
- 10 A method for production of tertiary phosphines in which the starting materials are inexpensive and easily handled, and which is adaptable to using either aryl or benzyl starting materials containing either halo or sulfonate ester substituents, would be highly
- 15 advantageous.

SUMMARY OF THE INVENTION

- 20 A method is provided for preparation of a compound of formula



- 25 wherein R^1 is aryl, alkenyl, cycloalkenyl or aralkyl, any of which may be substituted by one or more of the following: alkyl, aryl, alkoxy, alkanoyl, chloro, fluoro, alkoxycarbonyl, cyano, trifluoromethyl, cycloalkyl, or $CONR^4R^5$ wherein R^4 and R^5 are
- 30 independently hydrogen, alkyl, aryl or aralkyl; R^2 and R^3 are independently aryl, alkyl, or aralkyl, any of which may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl, chloro, fluoro, alkoxycarbonyl, cyano, trifluoromethyl,
- 35 cycloalkyl or $CONR^4R^5$ wherein R^4 and R^5 are independently hydrogen, alkyl, aryl or aralkyl; n is 2 where R^1 is a difunctional moiety, such as 1,1'-binaphth-2,2'-diyl,

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phenylene, or xylylene, and n is 1 in all other cases. The method comprises the step of treating a compound of formula R^1X_n ; wherein X is Cl, Br, I, or OSO_2Y ; wherein Y is alkyl, trihalomethyl, phenyl, halophenyl, or alkylphenyl; with a compound of formula R^2R^3PCl , a catalyst, and a reductant.

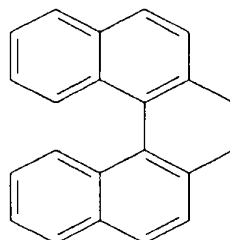
DETAILED DESCRIPTION OF THE INVENTION

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The following abbreviations and terminology are used herein. The term "alkyl" refers to a straight-chain or branched alkyl group having 1-30 carbon atoms which may be unsubstituted or substituted by fluoro, chloro, alkoxy, alkanoyl, cyano, alkoxy carbonyl, or cycloalkyl. The term "cycloalkyl" refers to a cyclic alkyl substituent having 3-20 carbon atoms. The term "alkenyl" refers to a straight-chain or branched group having 1-30 carbon atoms with at least one carbon-carbon double bond and which may be unsubstituted or substituted by fluoro, chloro, alkoxy, alkanoyl, cyano, alkoxy carbonyl, or cycloalkyl. The term "cycloalkenyl" refers to a cyclic alkenyl group having up to 20 carbon atoms. The term "alkoxy" refers to a substituent containing an alkyl group attached to, and bonded through an oxygen atom. The term "halo" refers to a substituent derived from fluorine, chlorine, bromine, or iodine. The term "aryl" refers to a substituent derived from any cyclic aromatic compound having 5-20 carbon atoms. The term "aralkyl" refers to an alkyl substituent substituted by an aryl group. The term "Ph" refers to a phenyl substituent. The term "dppe" refers to 1,2-bis-(diphenylphosphino)ethane. The term "triflate" refers to the trifluoromethanesulfonyl ester. The term "BINAP" refers to 2,2'-bis(diphenylphosphino)-1,1'-binaphthyl. The term

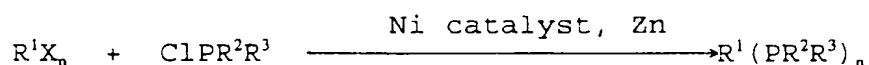
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"1,1'-binaphth-2,2'-diyl" refers to the divalent substituent moiety having the structure shown below.



5

In a preferred embodiment of this invention, an aryl, alkenyl, cycloalkenyl or aralkyl moiety substituted by a sulfonate ester or a halo substituent is reacted with a diarylchlorophosphine in the presence of a nickel catalyst and zinc, as shown in the following scheme:



15

If R^1 is aryl, the preferred moieties are phenyl, pyridyl, furyl, thienyl, pyrrolyl, naphthyl, 1,1'-binaphth-2,2'-diyl and its stereoisomers, or phenylene. The 1,1'-binaphth-2,2'-diyl and phenylene moieties are difunctional, and in these cases, n will be 2 in both the reactant and product in the above scheme. The other aryl moieties listed above are monofunctional, and thus n will be 1 for these. Any of the above aryl moieties may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl, chloro, fluoro, alkoxycarbonyl, cyano, trifluoromethyl, cycloalkyl, or $CONR^4R^5$ wherein R^4 and R^5 are independently hydrogen, alkyl, aryl or aralkyl.

30

If R^1 is aralkyl, the preferred moieties are benzyl, pyridylmethyl, furfuryl, thienylmethyl, pyrrolylmethyl,

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naphthylmethyl, or xylylene. The xylylene moiety is difunctional, and in this case, n will be 2 in both the reactant and product in the above scheme. The other arylmethyl moieties listed above are monofunctional, and thus n will be 1 for these. Any of the above arylmethyl moieties may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl, chloro, fluoro, alkoxycarbonyl, cyano, trifluoromethyl, cycloalkyl, or CONR^4R^5 wherein R^4 and R^5 are independently hydrogen, alkyl, aryl or aralkyl.

The reactive group attached to the R^1 moiety, represented by X in the scheme shown above, may be either a sulfonate ester or a halide. A sulfonate ester substituent on an aryl or aralkyl moiety may be, for example, alkylsulfonyloxy, trihalomethylsulfonyloxy, arylsulfonyloxy, haloarylsulfonyloxy, aralkylsulfonyloxy, or alkarylsulfonyloxy. The most preferred sulfonate ester substituent for carrying out the method of this invention is trifluoromethylsulfonyloxy, also known as triflate. X may also be a halo substituent. The most preferred halo substituent is bromo.

R^2 and R^3 may be independently alkyl, aryl, or aralkyl, any of which may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl, chloro, fluoro, alkoxycarbonyl, cyano, trifluoromethyl, cycloalkyl, or CONR^4R^5 wherein R^4 and R^5 are independently hydrogen, alkyl, aryl or aralkyl. Preferably, R^2 and R^3 are independently phenyl, alkyl, furyl, thienyl, pyrrolyl, pyridyl, benzyl, or naphthyl, any of which may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl, chloro, fluoro, alkoxycarbonyl, cyano, trifluoromethyl, cycloalkyl, or CONR^4R^5 wherein R^4 and R^5 are independently hydrogen, alkyl, aryl or aralkyl.

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The catalyst employed in this invention may be a nickel catalyst. Preferred nickel catalysts may be, for example, NiCl_2 , NiBr_2 , or NiZ_2L_m wherein Z is chloro or bromo and either L is $(\text{R}^6)_3\text{P}$ and m is 2, or L is $(\text{R}^6)_2\text{P}(\text{CH}_2)_k\text{P}(\text{R}^6)_2$ and m is 1; wherein R^6 is phenyl, phenyl substituted by one or more alkyl or alkoxy carbonyl substituents, alkyl, or cycloalkyl, and k is an integer between one and six, inclusive. The most preferred catalyst is $\text{NiCl}_2[\text{Ph}_2\text{P}(\text{CH}_2)_2\text{PPh}_2]$, otherwise referred to as $\text{NiCl}_2(\text{dppe})$.

A reductant is necessary to activate the chlorophosphine starting material, facilitating the catalyzed cross-coupling to produce the tertiary phosphine directly. Preferably, zinc may be used as a reductant in combination with a nickel catalyst. Most preferably, the zinc is preactivated by washing with hydrochloric acid, rinsing with water, and then drying. It is preferred to add the zinc to a mixture of the reactants and a solvent, maintaining the temperature between 5 and 15 °C during the addition.

Suitable solvents for the reaction carried out in this invention include the polar aprotic solvents, such as, for example, N,N-dimethylformamide (DMF), N,N-dimethylacetamide, N-methylpyrrolidone, and tetrahydrofuran. The most preferred solvent for carrying out the method of this invention is N,N-dimethylformamide. However, any solvent may be employed which allows for the preparation of tertiary phosphines using the method of this invention.

The reaction proceeds when the reactants are heated in the presence of the catalyst and the reductant. The reaction mixture is generally heated to a temperature in the range from about 60 to about 150 °C, preferably from about 80 to about 120 °C. The temperature is

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typically maintained within these ranges until the reaction is substantially complete as determined, for example, by the analysis of the reaction mixture by a technique such as gas chromatography to determine when
5 the starting materials have been depleted or when their levels are no longer decreasing. The reaction times may vary from about one hour to about 19 hours.

One advantage of the method of this invention over the
10 two known methods utilizing a cross-coupling reaction for production of tertiary phosphines is that aryl and aralkyl moieties bearing a halide substituent as well as those bearing a sulfonate ester substituent are suitable starting materials for the coupling reaction
15 of this invention. Each of the previous methods utilized either starting materials bearing a halide substituent or starting materials bearing a sulfonate ester substituent. Neither of these methods features both sulfonates and halides as potential starting
20 materials.

Another advantage of the method of this invention is that the diarylchlorophosphine starting materials, especially Ph_2PCl , are readily available, inexpensive,
25 and are not pyrophoric as are diphenylphosphine, (trimethylstannyl)diphenylphosphine and (trimethylsilyl)diphenylphosphine.

The examples which follow are intended as an
30 illustration of certain preferred embodiments of the invention, and no limitation of the invention is implied.

- 10 -

EXAMPLE 1

Preparation of BINAP from 1,1'-Binaphth-2,2'-diyl
ditriflate

5 To a solution of 8.25 g (30 mmol) of 1,1'-binaphth-
2,2'-diyl ditriflate in 40 ml DMF, was added all at
once 5.4 ml ClPPh₂ (30 mmol) and 500 mg NiCl₂(dppe)
(0.95 mmol). Zinc powder (2.31 g, 36 mmol) was added
portionwise to the reaction mixture with vigorous
10 mechanical stirring while the mixture was cooled
externally in an ice-water bath. The mixture was then
heated with stirring at 100 °C for 19 hours. Then, the
mixture was cooled to room temperature, filtered and
washed twice with 10 ml methanol. The isolated solid
15 (5 g) had a purity of 96-97%, as determined by gas
chromatographic analysis. Further purification was
conducted by continuous extraction with methylene
chloride in a soxhlet apparatus; substantially pure
product was extracted, leaving zinc salts behind in the
20 residue. The overall yield of BINAP was 52%.

EXAMPLE 2

Preparation of Methyl 2-(diphenylphosphino)benzoate

25 To a solution of 17.08 g (58 mmol) of methyl
2-(trifluoromethylsulfonyloxy)benzoate in 95 ml DMF,
were added 1.163 g NiCl₂(dppe) (2.2 mmol) and 10.8 ml
ClPPh₂ (60 mmol). The reaction mixture was cooled in
ice-water bath, and 5.3 g zinc (83 mmol) was added
portionwise at 8-15 °C. The reaction mixture was
30 heated to 108 °C for 4 hours, then filtered while at 80
°C. One third of the filtrate volume was stripped
under reduced pressure. After refrigeration of the
filtrate overnight, 8.66 g of the title compound having
35 a purity of greater than 97% was recovered.

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The workup was repeated and the filtrate yielded a second crop of title compound (3.87 g) with a purity of greater than 97%.

5 The filtrate was evaporated in vacuo to remove volatiles, producing a viscous oil. Chromatography of this oil on silica-gel using 20% ethyl acetate in hexane as an eluent provided 3.3 g of the desired product. The overall yield was 82-84%.

10

EXAMPLE 3

Preparation of Methyl 2-(diphenylphosphino)naphthalene
from 2-Bromonaphthalene

15 To a solution of 4.14 g (20 mmol) of 2-bromonaphthalene in 40 ml DMF, was added 0.376 g $\text{NiCl}_2(\text{dppe})$ (0.712 mmol). The reaction mixture was cooled to 0 °C and 3.6 ml ClPPh_2 (20 mmol) was added dropwise followed by the portionwise addition of 1.74 g zinc (27 mmol)
20 while the internal temperature was kept at 8-14 °C. The reaction mixture was heated to 100 °C for 2 hours, at which point 89% conversion of the substrate was observed by gas chromatographic analysis. The reaction was filtered while hot through a short pad of silica
25 gel, and the filtrate was concentrated to one-third volume under reduced pressure. The filtrate was cooled overnight at -10 °C and yielded 3.66 g of the title compound having greater than 97% purity. The volatiles were removed from the filtrate in vacuo to yield an
30 additional 3.2 g of product with the following composition:

Naphthalene 6%

2-Bromonaphthalene 7%

Product 78%

35 Total yield: 91%.

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EXAMPLE 4

Preparation of Benzyldiphenylphosphine from Benzyl Bromide

5 To a solution of 2.7 ml benzyl bromide (20 mmol) in
40 ml DMF, was added 0.436 g $\text{NiCl}_2(\text{dppe})$ (0.826 mmol).
The reaction mixture was cooled to 5 °C and 3.6 ml
 ClPPh_2 (20 mmol) was added dropwise followed by the
portionwise addition of 1.74 g zinc (27 mmol) while the
10 internal temperature was kept at 8-14 °C. The reaction
mixture was heated to 83 °C for 45 minutes at which
time 81% conversion to the title compound was observed
by gas chromatographic analysis.

15

EXAMPLE 5

Preparation of (S)-BINAP from (S)-1,1'-Binaphth-2,2'-diyl ditriflate

To preactivated zinc powder (1.34 g, 21 mmol), prepared
20 by washing zinc with hydrochloric acid and water and
then drying, in 5 ml tetrahydrofuran and a crystal of
iodine, was added (S)-1,1'-binaphth-2,2'-diyl
ditriflate (3.82 g, 6.9 mmol) in DMF dropwise over 30
minutes at 45 °C. The reaction mixture was cooled to
25 room temperature and $\text{NiCl}_2(\text{dppe})$ (362 mg, 0.68 mmol) was
added at once, followed by the dropwise addition of
 ClPPh_2 (2.5 ml, 13.8 mmol) in 8 ml DMF over 15 minutes
at 4-7 °C, and the mixture was heated with stirring at
100 °C for 19 hours. The reaction was monitored by gas
30 chromatography until starting material was depleted.
The dark reddish mixture was filtered while hot. A
solid precipitated upon cooling which was collected by
filtration and washed with two 5 ml portions of
methanol to give 0.54 g of (S)-BINAP.

35

The filtrate was allowed to stand overnight at 5 °C,
yielding 0.81 g of crude product. After flash
chromatography on a silica gel column, 0.7 g of a white

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crystalline material (94% purity by gas chromatography) was recovered. This material had a melting point of 41 °C, identical to the literature value, and $[\alpha]^D = -210$ (benzene, $c=0.1$) at 20 °C {literature: $[\alpha]^D = -208$ (benzene, $c=0.5$) at 20 °C}.

EXAMPLE 6

Preparation of 1-Carbomethoxy-2-(diphenylphosphino)naphthalene

10

To a solution of 66.6 g (0.195 mol) of 1-carbomethoxy-2-(trifluoromethylsulfonyloxy)naphthalene in 450 ml DMF were added, under a nitrogen atmosphere, 3.65 g $\text{NiCl}_2(\text{dppe})$ (6.9 mmol) and 35 ml ClPPh_2 (0.195 mol). The reaction mixture was cooled in an ice-water bath and 15 g zinc (20% excess) was added portionwise at 8-15 °C. The mixture was then heated to 108 °C for 2 hours, cooled to 50 °C, filtered through silica and washed with three 20 ml portions of methanol. The filtrate was concentrated under vacuum to half of its original volume and allowed to crystallize at 0-4 °C. The product was collected and washed with methanol. Further concentration of the filtrate caused additional material to crystallize. The total yield of the title compound was 66.3 g (92%).

EXAMPLE 7

Preparation of 1-Benzylamido-2-(diphenylphosphino)benzene

30

To a solution of 4.7 g (13 mmol) 2-trifluoromethanesulfonyloxy-N-benzylbenzamide in DMF (50 ml) were added $\text{NiCl}_2(\text{dppe})$ (0.336 g, 0.64 mmol) and Ph_2PCl (2.5 ml, 13.9 mmol) under a nitrogen atmosphere. The reaction mixture was cooled with an ice bath and zinc (0.98 g, 15 mmol) was added portionwise at 5-10 °C. The reaction mixture was then heated to 108 °C and monitored by gas chromatography. After 12 hours, a

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conversion of 73% was observed. The mixture was cooled to room temperature and then filtered through a pad of silica gel. The filtrate was diluted with water (100 ml) and extracted with two 50 ml portions of
5 dichloromethane. Solvent was removed under reduced pressure and the residual paste was crystallized from hot dichloromethane-hexane-methanol to yield 3.74 g (67%) of material in the form of white needles with a melting point of 160 °C. The ¹H NMR and mass spectrum
10 of this material were consistent with the title compound.

EXAMPLE 8

Cross-Coupling of Benzyl Bromide and Ph₂PCL in THF

15 To a solution of benzyl bromide (3.42 g, 20 mmol) in THF (50 ml) was added NiCl₂(dppe) (0.275 g, 0.52 mmol). The reaction mixture was cooled with an ice bath and Ph₂PCL (3.6 ml, 20 mmol) was added dropwise, followed by
20 portionwise addition of zinc (1.57 g, 24 mmol), while maintaining the reaction temperature in the range between 5 and 9 °C. The reaction mixture was then warmed to room temperature and maintained there for 1.25 hours, at which time complete disappearance of
25 starting material and 85% conversion to product were observed by gas chromatography. The mixture was filtered while hot through a pad of silica gel. Removal of solvent under reduced pressure produced an oil, which was diluted with water (50 ml) and extracted
30 with two 20 ml portions of dichloromethane. The organic layers were combined and the solvent was removed under reduced pressure to produce a white residue that was recrystallized from hexane-dichloromethane to give a white crystalline material,
35 found to be the oxide of benzyldiphenylphosphine due to the air sensitivity of the phosphine, in greater than 90% yield.

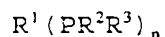
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Other variations and modifications of this invention will be obvious to those skilled in the art. This invention is not limited except as set forth in the claims.

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WHAT IS CLAIMED IS:

1. A method for preparation of a compound of formula



wherein R^1 is aryl, alkenyl, cycloalkenyl or aralkyl, any of which may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl, chloro, fluoro, alkoxycarbonyl, cyano, trifluoromethyl, cycloalkyl or $CONR^4R^5$ wherein R^4 and R^5 are independently hydrogen, alkyl, aryl or aralkyl; R^2 and R^3 are independently aryl, alkyl, or aralkyl, any of which may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl, chloro, fluoro, alkoxycarbonyl, cyano, trifluoromethyl, or cycloalkyl; n is 2 where R^1 is a difunctional moiety, and n is 1 for any other R^1 ; said method comprising the step of treating a compound of formula R^1X_n ; wherein X is Cl, Br, I, or OSO_2Y ; wherein Y is alkyl, trihalomethyl, phenyl, halophenyl, or alkylphenyl; with a compound of formula R^2R^3PCl in the presence of a catalyst and a reductant.

2. The method of claim 1 wherein R^1 is phenyl, benzyl, naphthyl, naphthylmethyl, 1,1'-binaphth-2,2'-diyl, pyridyl, pyridylmethyl, furyl, furfuryl, thienyl, thienylmethyl, pyrrolyl, pyrrolylmethyl, phenylene, or xylylene, any of which may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl, chloro, fluoro, alkoxycarbonyl, cyano, trifluoromethyl, cycloalkyl or $CONR^4R^5$ wherein R^4 and R^5 are independently hydrogen, alkyl, aryl or aralkyl; and R^2 and R^3 are independently phenyl, alkyl, furyl, thienyl, pyrrolyl, pyridyl, benzyl, or naphthyl, any of which may be substituted by one or more of the following: alkyl, aryl, aralkyl, alkoxy, alkanoyl,

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chloro, fluoro, alkoxycarbonyl, cyano, trifluoromethyl, cycloalkyl, or CONR^4R^5 wherein R^4 and R^5 are independently hydrogen, alkyl, aryl or aralkyl; n is 2 where R^1 is 1,1'-binaphth-2,2'-diyl, phenylene, or xylylene, and n is 1 for any other R^1 .

3. The method of claim 2 wherein the catalyst is a nickel compound.

4. The method of claim 3 wherein zinc is the reductant.

5. The method of claim 4 wherein the nickel compound is NiZ_2 or a compound of formula NiZ_2L_m wherein Z is chloro or bromo; L is $(\text{R}^6)_3\text{P}$ and m is 2, or L is $(\text{R}^6)_2\text{P}(\text{CH}_2)_k\text{P}(\text{R}^6)_2$, and m is 1; wherein R^6 is phenyl, phenyl substituted by one or more alkyl or alkoxycarbonyl substituents, alkyl, or cycloalkyl, and k is an integer between one and six, inclusive.

6. The method of claim 5 wherein the nickel compound is [1,2-bis(diphenylphosphino)ethane]nickel(II) chloride.

7. The method of claim 6 wherein R^2 and R^3 are phenyl.

8. The method of claim 7 wherein R^1 is 1,1'-binaphth-2,2'-diyl.

9. The method of claim 8 wherein X is OSO_2Y and Y is trifluoromethyl.

10. The method of claim 7 wherein R^1 is (S)- 1,1'-binaphth-2,2'-diyl.

11. The method of claim 7 wherein R^1 is (R)- 1,1'-binaphth-2,2'-diyl.

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12. The method of claim 10 wherein X is OSO_2Y and Y is trifluoromethyl.
13. The method of claim 11 wherein X is OSO_2Y and Y is trifluoromethyl.
14. The method of claim 7 wherein R^1 is 1-carbomethoxy-2-naphthyl.
15. The method of claim 14 wherein X is OSO_2Y and Y is trifluoromethyl.
16. The method of claim 4 wherein R^2 and R^3 are phenyl.
17. The method of claim 4 wherein R^1 is (S)-1,1'-binaphth-2,2'-diyl.
18. The method of claim 4 wherein R^1 is (R)-1,1'-binaphth-2,2'-diyl.

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/US 98/06003

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C07F9/50

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C07F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 268 526 A (SOCIÉTÉ NATIONALE DES POUDRES ET EXPLOSIFS) 25 May 1988 see the whole document ---	1-18
Y	US 5 399 771 A (DONGWEI CAI) 21 March 1995 cited in the application see the whole document ---	1-18
Y	TUNNEY S E ET AL: "PALLADIUM-CATALYZED COUPLING OF ARYL HALIDES WITH (TRIMETHYLSTANNYL)DIPHENYLPHOSPHINE AND (TRIMETHYLSILYL)DIPHENYLPHOSPHINE" JOURNAL OF ORGANIC CHEMISTRY, vol. 52, no. 5, 1 January 1987, pages 748-753, XP002006947 cited in the application see the whole document ---	1-18
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☒ Further documents are listed in the continuation of box C

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

29 May 1998

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Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel: (+31-70) 340-2040, Tx: 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Beslier, L

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/06003

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